

## CHAPTER 6

### CYCLONES AND MULTICYCLONES

#### 6-1. Cyclone

The cyclone is a widely used type of particulate collection device in which dust-laden gas enters tangentially into a cylindrical or conical chamber and leaves through a central opening. The resulting vortex motion or spiraling gas flow pattern creates a strong centrifugal force field in which dust particles, by virtue of their inertia, separate from the carrier gas stream. They then migrate along the cyclone walls by gas flow and gravity and fall into a storage receiver. In a boiler or incinerator installation this particulate is composed of fly-ash and unburned combustibles such as wood char. Two widely used cyclones are illustrated in figure 6-1.

#### 6-2. Cyclone types

*a.* Cyclones are generally classified according to their gas inlet design and dust discharge design, their gas handling capacity and collection efficiency, and their arrangement. Figure 6-2 illustrates the various types of gas flow and dust discharge configurations employed in cyclone units. Cyclone classification is illustrated in table 6-1.

*b. Conventional cyclone.* The most commonly used cyclone is the medium efficiency, high gas throughput (conventional) cyclone. Typical dimensions are illustrated in figure 6-3. Cyclones of this type are used primarily to collect coarse particles when collection efficiency and space requirements are not a major consideration. Collection efficiency for conventional cyclones on 10 micron particles is generally 50 to 80 percent.

*c. High efficiency cyclone.* When high collection efficiency (80-95 percent) is a primary consideration in cyclone selection, the high efficiency single cyclone is commonly used (See figure 6-4). A unit of this type is usually smaller in diameter than the conventional cyclone, providing a greater separating force for the same inlet velocity and a shorter distance for the particle to migrate before reaching the cyclone walls. These units may be used singly or arranged in parallel or series as shown in figure 6-5. When arranged in parallel they have the advantage of handling larger gas volumes at increased efficiency for the same power consumption of a conventional unit. In parallel they also have the ability to reduce headroom space requirements below that of a single cyclone handling the same gas volumes by varying the number of units in operation.

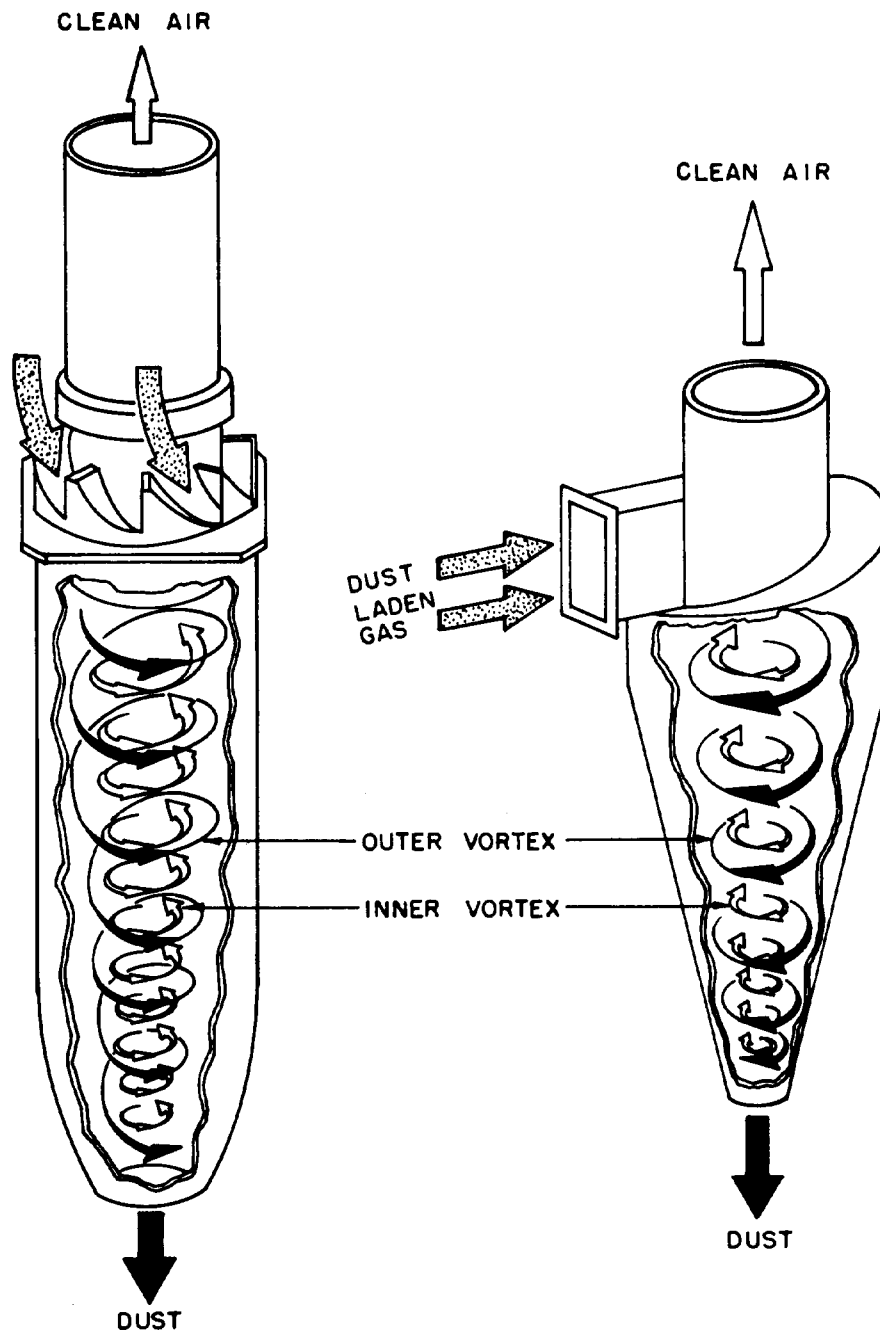
*d. Multicyclones.* When very large gas volumes must

be handled and high collection efficiencies are needed a multiple of small diameter cyclones are usually nested together to form a multicyclone. A unit of this type consists of a large number of elements joined together with a common inlet plenum, a common outlet plenum, and a common dust hopper. The multicyclone elements are usually characterized by having a small diameter and having axial type inlet vanes. Their performance may be hampered by poor gas distribution to each element, fouling of the small diameter dust outlet, and air leakage or back flow from the dust bin into the cyclones. These problems are offset by the advantage of the multicyclone's increased collection efficiency over the single high efficiency cyclone unit. Problems can be reduced with proper plenum and dust discharge design. A typical fractional efficiency curve for multi-cyclones is illustrated in figure 6-6.

*e. Wet or irrigated cyclone.* Cyclones may be operated wet in order to improve efficiency and prevent wall buildup or fouling (See fig. 6-7). Efficiency is higher for this type of operation because dust particles, once separated, are trapped in a liquid film on the cyclone walls and are not easily re-entrained. Water is usually sprayed at the rate of 5 to 15 gallons per 1,000 cubic feet (ft<sup>3</sup>) of gas. Wet operation has the additional advantages of reducing cyclone erosion and allowing the hopper to be placed remote from the cyclones. If acids or corrosive gases are handled, wet operation may result in increased corrosion. In this case, a corrosion resistant lining may be needed. Re-entrainment caused by high values of tangential wall velocity or accumulation of liquid at the dust outlet can occur in wet operation. However, this problem can be eliminated by proper cyclone operation. Wet operation is not currently a common procedure for boilers and incinerators.

#### 6-3. Cyclone collection efficiency

*a. Separation ability.* The ability of a cyclone to separate and collect particles is dependent upon the particular cyclone design, the properties of the gas and the dust particles, the amount of dust contained in the gas, and the size distribution of the particles. Most efficiency determinations are made in tests on a geometrically similar prototype of a specific cyclone design in which all of the above variables are accurately known. When a particular design is chosen it is usually accurate to estimate cyclone collection efficiency based upon the cyclone manufacturer's



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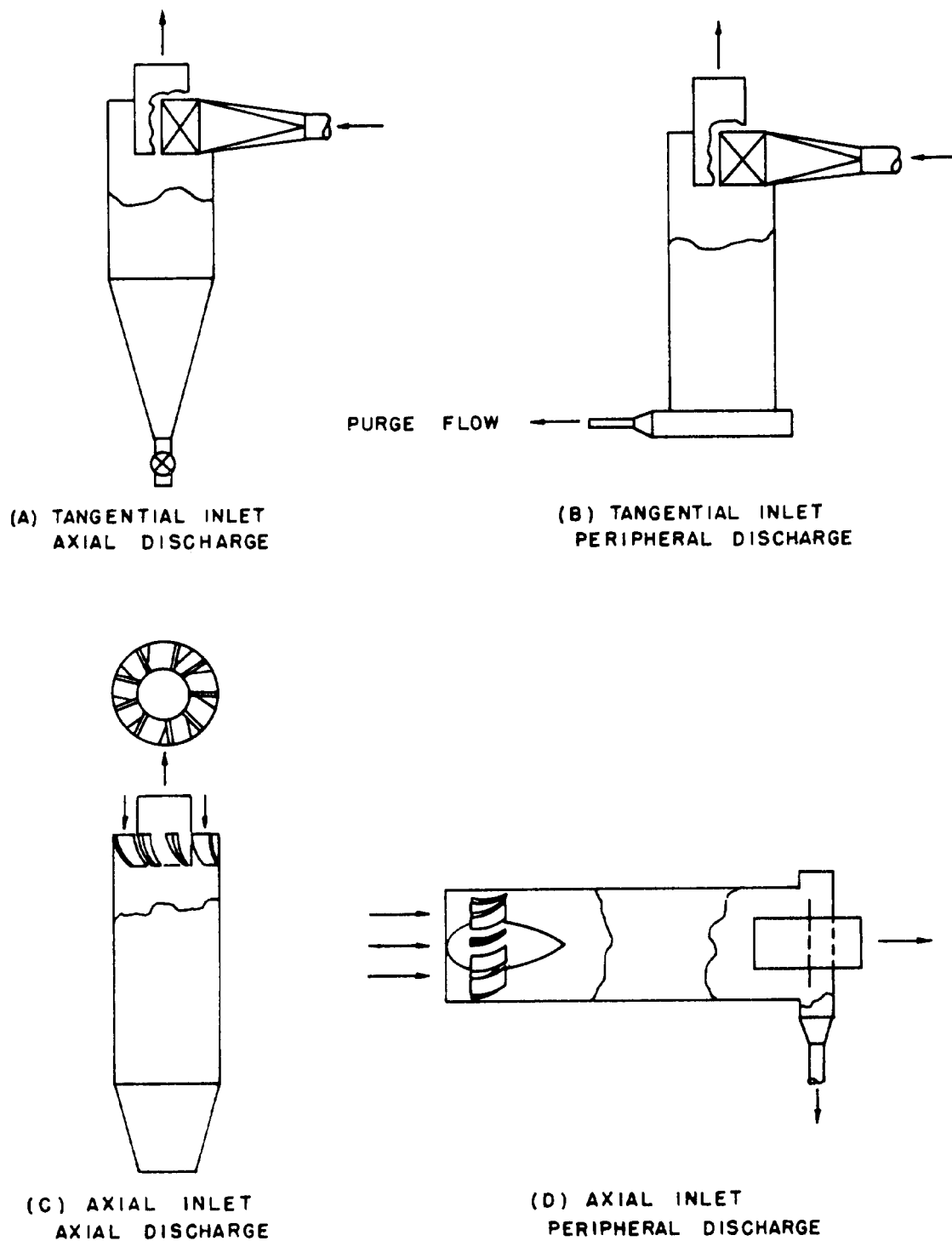
Figure 6-1. Cyclone configuration

efficiency curves for handling a similar dust and gas. All other methods of determining cyclone efficiency are estimates and should be treated as such.

*b. Predicting cyclone collection efficiency.* A particle size distribution curve for the gas entering a cyclone is used in conjunction with a cyclone fractional

efficiency curve in order to determine overall cyclone collection efficiency.

- (1) A particle size distribution curve shows the weight of the particles for a given size range in a dust sample as a percent of the total weight of the sample. Particle size



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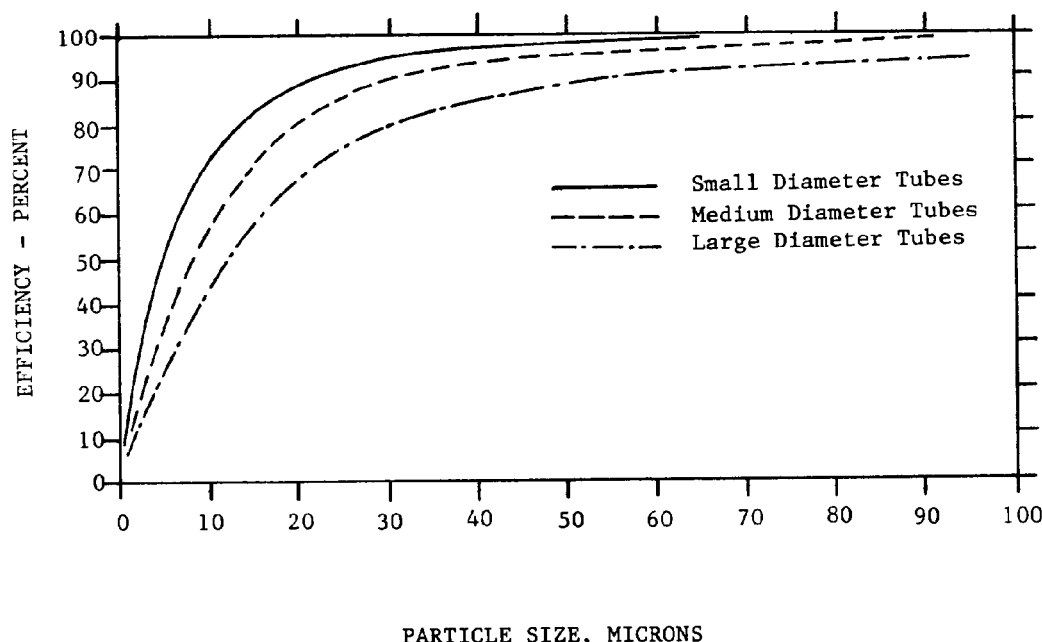
Figure 6-2. Types of cyclones in common use.

TABLE 6-1  
CYCLONE CLASSIFICATION

Type	Body Diameter (ft.)	Gas Flow (ft <sup>3</sup> /min)	Pressure Drop (in H <sub>2</sub> O)	Inlet Velocity ft/s	Collection Efficiency (%)	Application	Other
Conventional	4-12	1,000-20,000	.5-2	20-70	50-80	Material handling Exhaust gas precleaner	Large headroom requirements. Limited to large coarse particulates, large grain loadings.
High efficiency single cyclone	less than 3	100-2,000	2-6	50-70	80-95	Industrial boiler particulate control	Smaller space requirement. Parallel arrangement, inlet vane flow controls needed continuous dust removal system purge operation.
Multi-cyclones	.5-1	30,000 and up	3-6	50-70	90-95	Industrial and utility boiler. Particulate control	Plenums required. Problems: gas recirculation fouling. Continuous dust removal system, flow control.
Irrigated cyclone (wet) high efficiency single unit	less than 3	100-2,000	2-6	50	90-95	Boiler application (low sulfur fuel) (low gas temperature).	Water rate 5-15 gal/1,000 ft <sup>3</sup> /min. Corrosion resistant materials.

NOTE: Cyclone collection efficiency must be evaluated for each specific application due to the sensitivity of cyclone performance on gas and dust properties and loadings. Refer to Table 6-8 for expected collection efficiency estimates.

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ADAPTED FROM EPA-450/3-81-005a,  
CONTROL TECHNIQUES FOR  
PARTICULATE EMISSIONS FROM  
STATIONARY SOURCES

Figure 6-3. Relative effect of cyclone dimensions on efficiency.

distributions are determined by gas sampling and generally conform to statistical distributions. See figure 6-8.

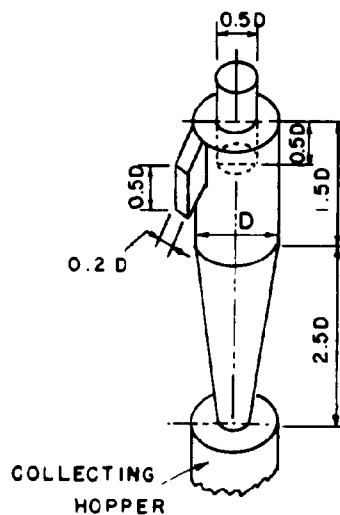
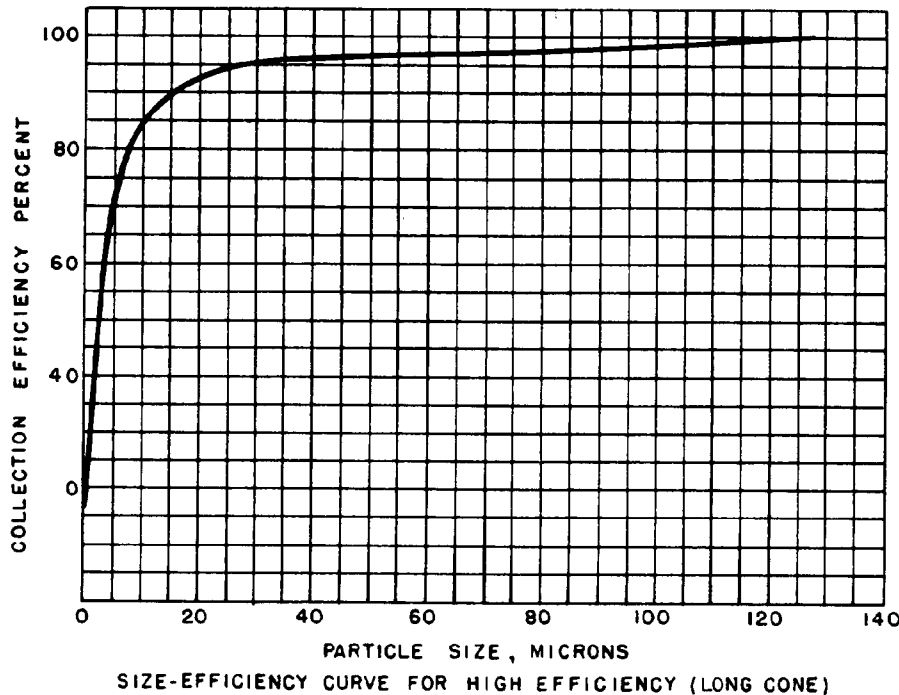
- (2) A fractional cyclone efficiency curve is used to estimate what weight percentage of the particles in a certain size range will be collected at a specific inlet gas flow rate and cyclone pressure drop. A fractional efficiency curve is best determined by actual cyclone testing and may be obtained from the cyclone manufacturer. A typical manufacturer's fraction efficiency curve is shown on figure 6-9.
- (3) Cyclone collection efficiency is determined by multiplying the percentage weight of particles in each size range (size distribution curve) by the collection efficiency corresponding to that size range (fractional efficiency curve), and adding all weight collected as a percentage of the total weight of dust entering the cyclone.

#### 6-4. Cyclone pressure drop and energy requirements

*a. Pressure drop.* Through any given cyclone there will be a loss in static pressure of the gas between the

inlet ductwork and the outlet ductwork. This pressure drop is a result of entrance and exit losses, frictional losses and loss of rotational kinetic energy in the exiting gas stream. Cyclone pressure drop will increase as the square of the inlet velocity.

*b. Cyclone energy requirements.* Energy requirements in the form of fan horsepower are directly proportional to the volume of gas handled and the cyclone resistance to gas flow. Fan energy requirements are estimated at one quarter horsepower per 1000 cubic feet per minute (cfm) of actual gas volume per one inch, water gauge, pressure drop. Since cyclone pressure drop is a function of gas inlet and outlet areas, cyclone energy requirements (for the same gas volume and design collection efficiency) can be minimized by reducing the size of the cyclone while maintaining the same dimension ratios. This means adding more units in parallel to handle the required gas volume. The effect on theoretical cyclone efficiency of using more units in parallel for a given gas volume and system pressure drop is shown in figure 6-10. The increased collection efficiency gained by compounding cyclones in parallel can be lost if gas recirculation among individual units is allowed to occur.



#### HIGH EFFICIENCY SINGLE CYCLONE UNIT (LONG CONE)

##### DESIGN CRITERIA

100 - 2,000 ft<sup>3</sup>/min

50 - 70 ft/s

D - LESS THAN 3 FEET

P - 2 TO 6 in H<sub>2</sub>O

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Figure 6-4. Efficiency curve and dimensions for a high efficiency single cyclone

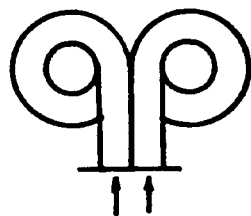
## 6-5. Application

*a. Particulate collection.* Cyclones are used as particulate collection devices when the particulate dust is coarse, when dust concentrations are greater than 3 grains per cubic foot (gr/ft<sup>3</sup>), and when collection efficiency is not a critical requirement. Because collection efficiencies are low compared to other collection equipment, cyclones are often used as pre-cleaners for

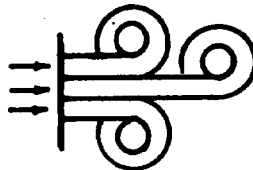
other equipment or as a final cleaner to improve overall efficiency.

*b. Pre-cleaner.* Cyclones are primarily used as pre-cleaners in solid fuel combustion systems such as stoker fired coal burning boilers where large coarse particles may be generated. The most common application is to install a cyclone ahead of an electrostatic precipitator. An installation of this type is particularly

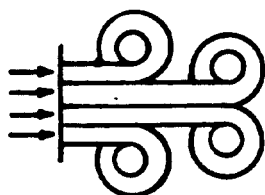
a. Parallel



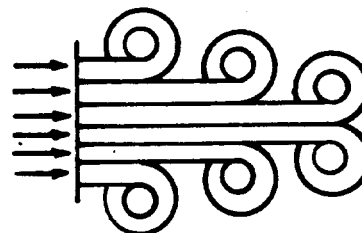
TWIN CYCLONES



GROUP OF THREE CYCLONES

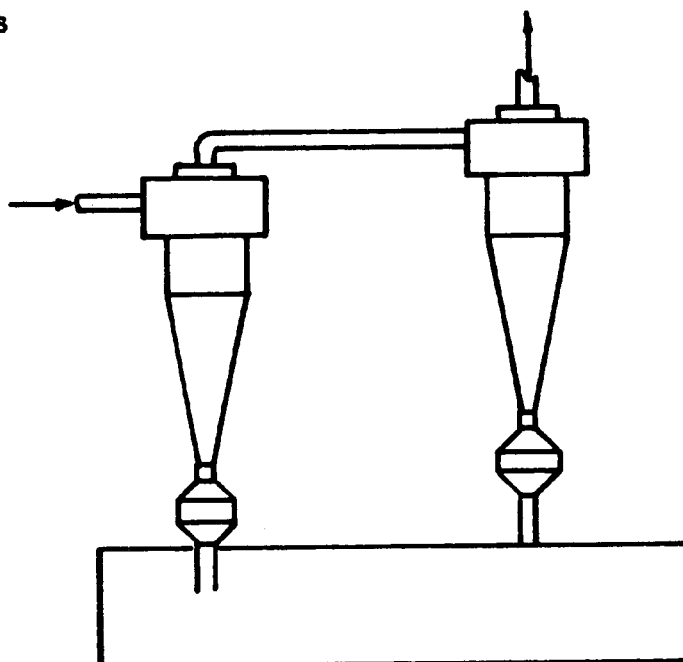


GROUP OF FOUR CYCLONES



GROUP OF SIX CYCLONES

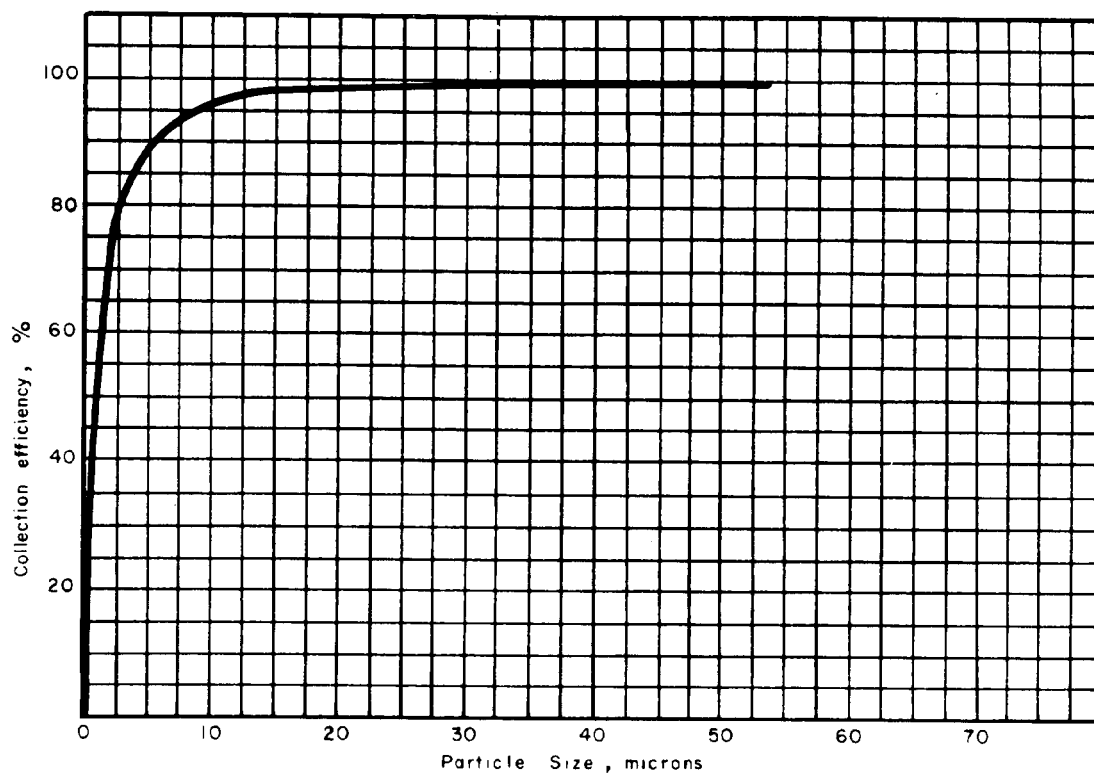
b. Series



SERIES CYCLONE ARRANGEMENT

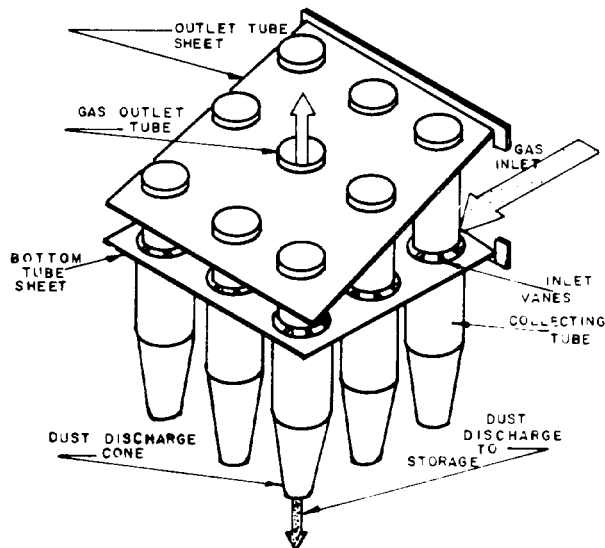
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Figure 6-5. Parallel and series arrangements for cyclones.



SIZE-EFFICIENCY CURVE FOR SMALL-DIAMETER MULTIPLE CYCLONE

### HIGH EFFICIENCY MULTIPLE CYCLONE UNITS (MULTICLONES)



#### DESIGN CRITERIA

30,000 - 100,000 ft<sup>3</sup>/min

50 - 70 ft/s

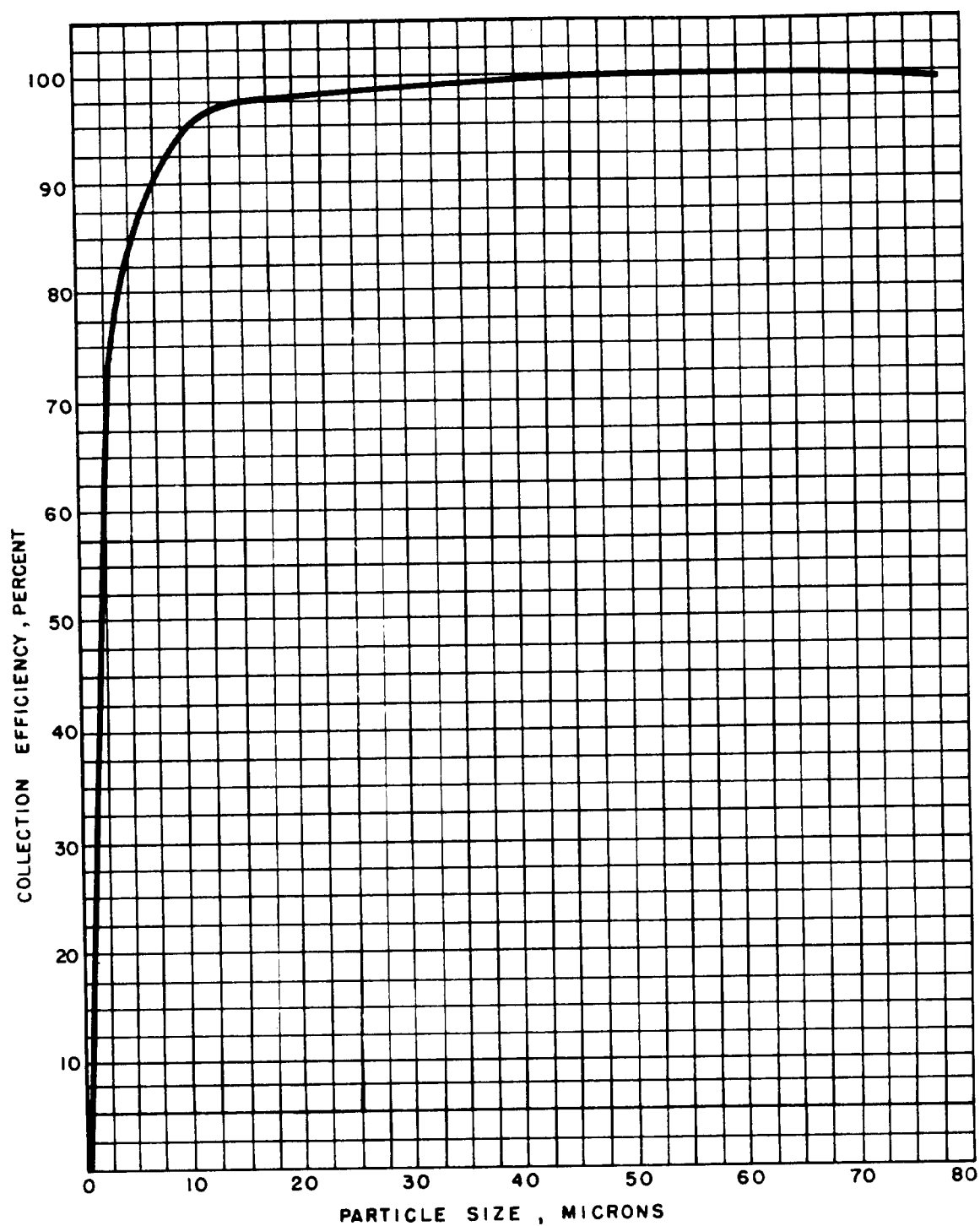
D - 6-12 inches

$\Delta p$  - 3 to 6 inH<sub>2</sub>O

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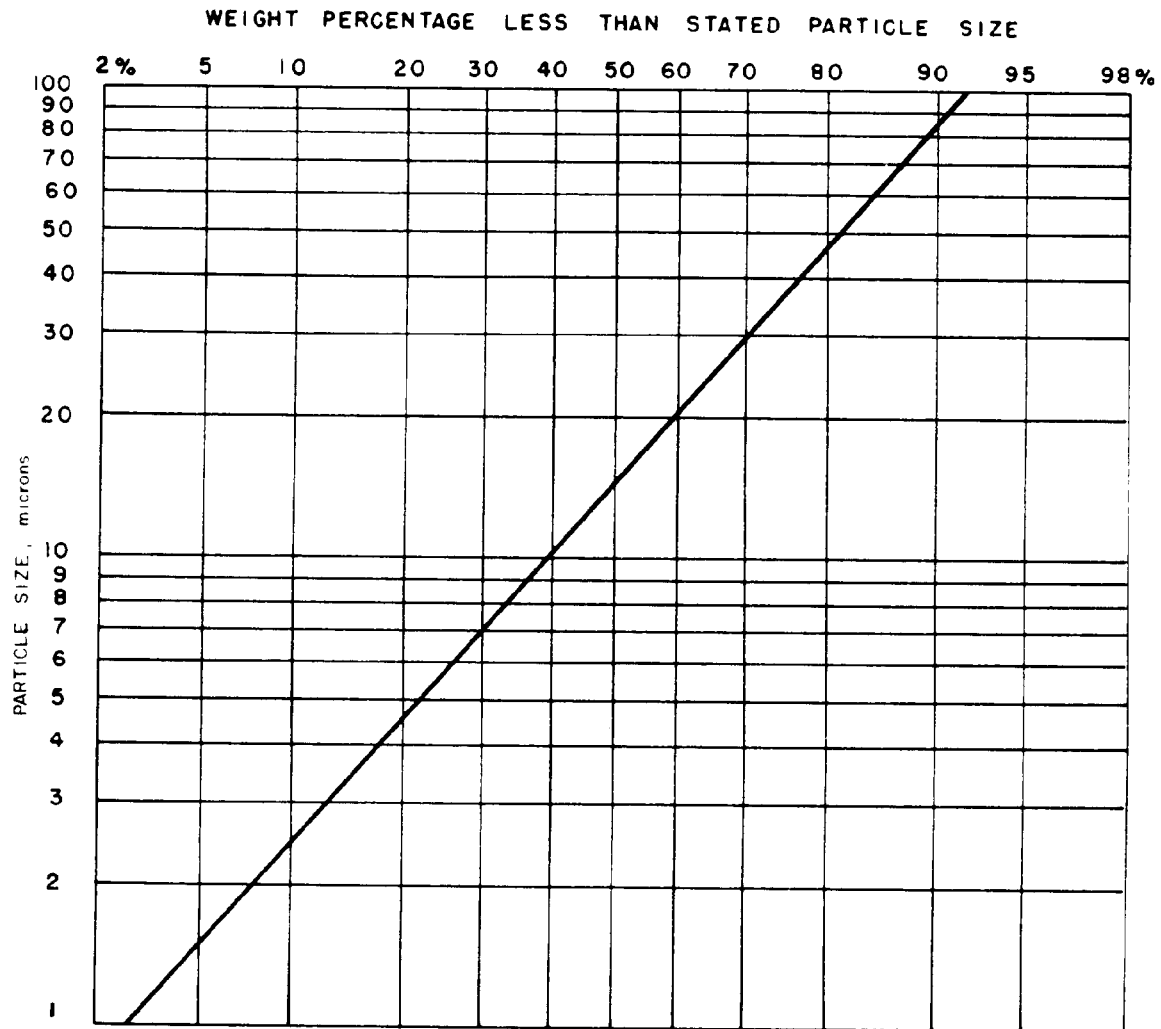
Figure 6-6. Efficiency curve and illustration of a multicyclone unit.





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Figure 6-7. Size-efficiency curve for high-efficiency (long cone) irrigated cyclone.



PARTICLE SIZE DISTRIBUTIONS OF PARTICULATE EMITTED  
FROM UNCONTROLLED POWER PLANTS  
(PULVERIZED COAL FIRED BOILER) (7)

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Figure 6-8. Particle size distribution curve (by weight) of particulate emitted from uncontrolled power

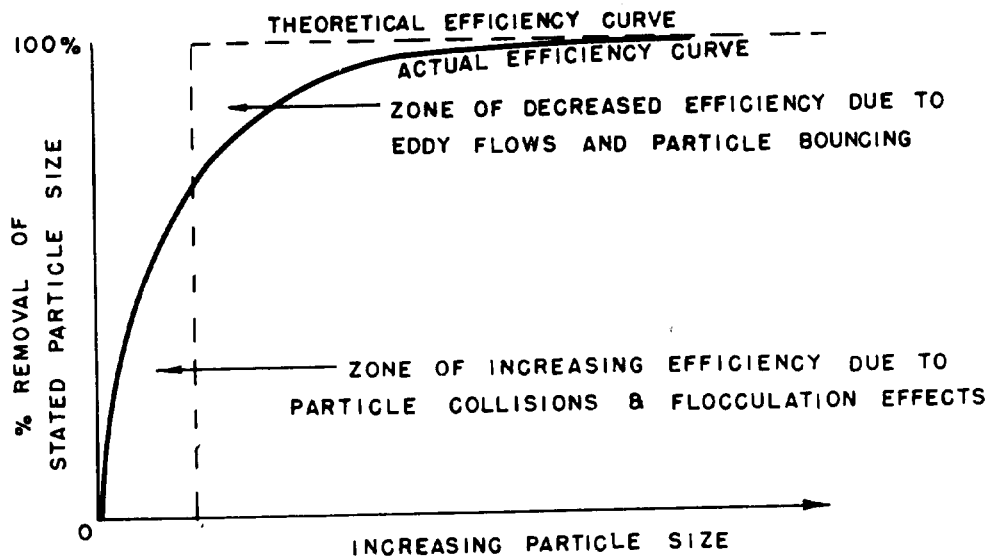
efficient because the cyclone exhibits an increased collection efficiency during high gas flow and dust loading conditions, while the precipitator shows an increase in collection efficiency during decreased gas flow and dust loading. The characteristics of each type of equipment compensate for the other, maintaining good efficiency over a wide range of operating flows and dust loads. Cyclones are also used as pre-cleaners when large dust loads and coarse abrasive particles may affect the performance of a secondary collector.

They can also be used for collection of unburned particulate for re-injection into the furnace.

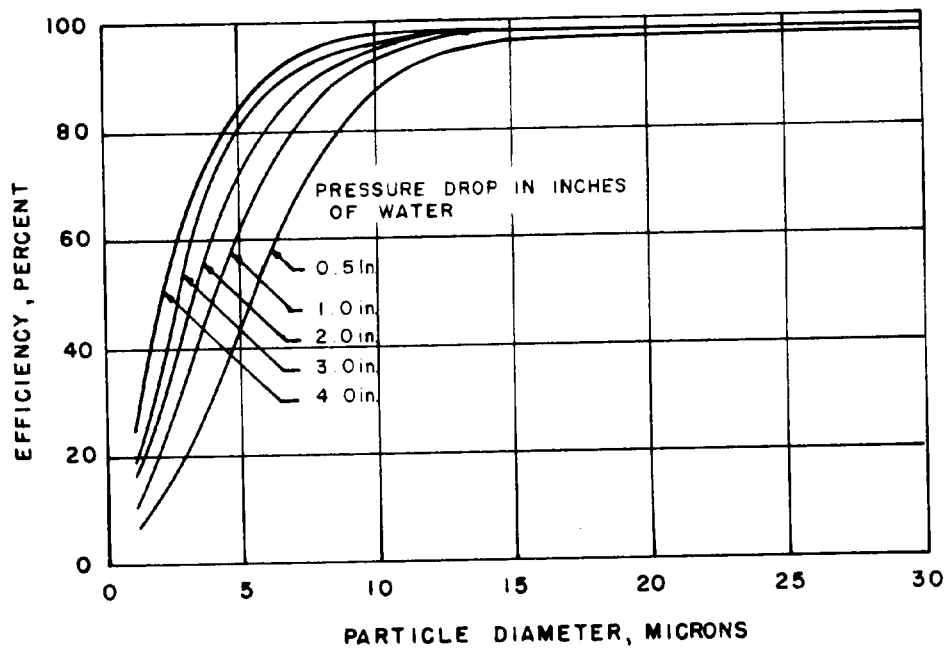
c. *Fine particles.* Where particularly fine sticky dust must be collected, cyclones more than 4 to 5 feet in diameter do not perform well. The use of small diameter multicyclones produces better results but may be subject to fouling. In this type of application, it is usually better to employ two large diameter cyclones in series.

d. *Coarse particles.* when cyclones handle coarse

a. THEORETICAL FRACTIONAL EFFICIENCY CURVE

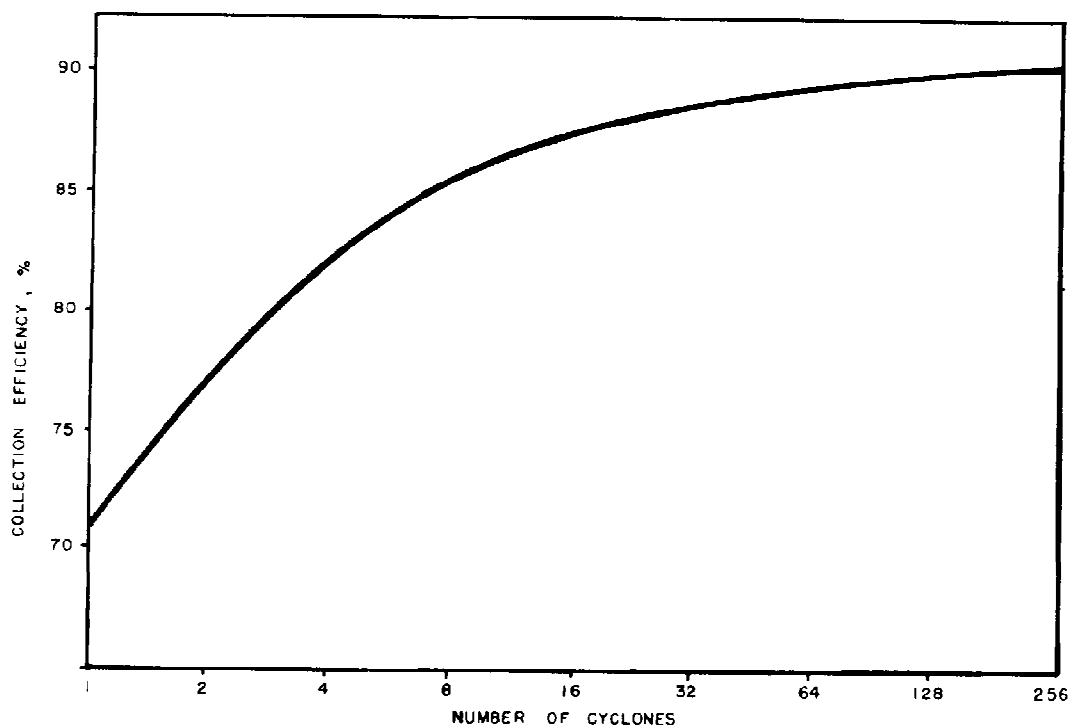


b. TYPICAL MANUFACTURER'S FRACTIONAL EFFICIENCY CURVE



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Figure 6-9. Fractional efficiency curves



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Figure 6-10. Effect of smaller cyclones in parallel on theoretical cyclone collection efficiency

particles, they are usually designed for low inlet velocities 5-10 feet per second (ft/sec). This is done to minimize erosion on the cyclone walls and to minimize breakdown of coarser particles that would normally be separated, into particles too fine for collection.

*e. Limited space.* In cases where cyclones must be erected in limited space, smaller diameter multi-cyclones have an obvious space advantage over larger diameter units. Small cyclones also have the advantage of increased efficiency over a single unit handling the same gas capacity, although this advantage is sometimes lost by uneven gas distribution to each unit with resultant fouling of some elements.

## 6-6. Cyclone performance

*a. Collection efficiency and pressure drop.* For any given cyclone it is desirable to have as high a collection efficiency and as low a pressure drop as possible. Unfortunately, changes in design or operating variables which tend to increase collection efficiency also tend to increase pressure drop at a greater rate than the collection efficiency. Efficiency will increase with an increase in particle size, particle density, gas inlet velocity, cyclone body or cone length, and the ratio of body diameter to gas outlet diameter. Decreased efficiency is caused by an increase in gas viscosity, gas density, cyclone diameter; gas outlet diameter; and inlet widths or area. The effect on theoretical collection efficiency

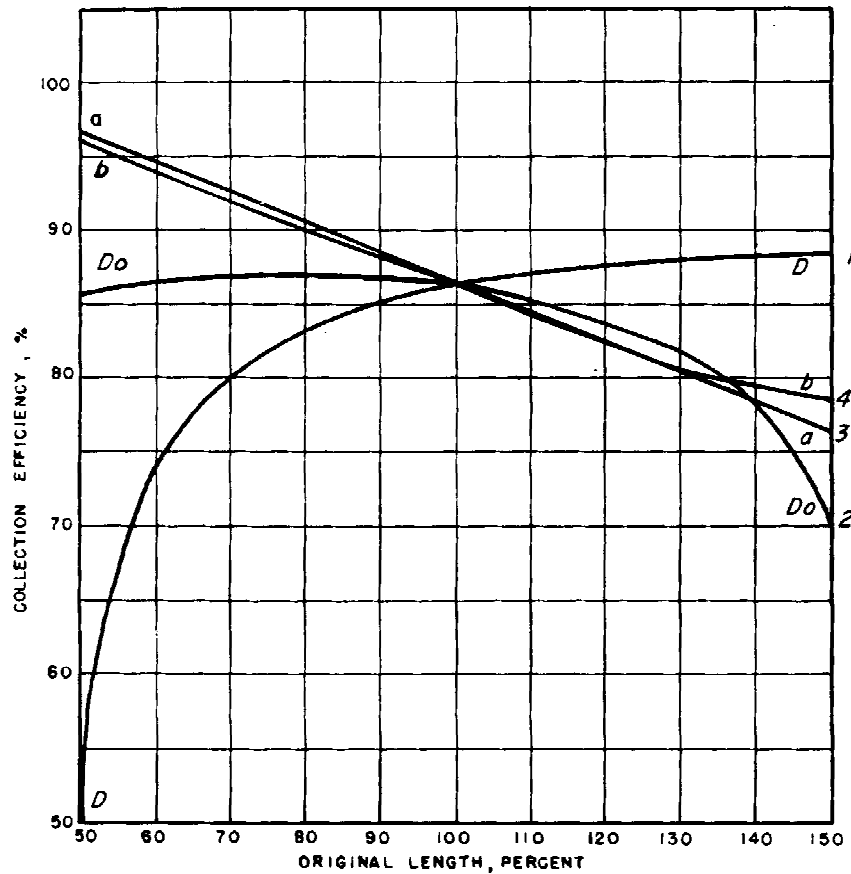
of changing the dimensions of an 8 inch diameter cyclones is shown in figure 6-11. The effects of changing gas inlet velocity, grain loading, particle specific gravity, gas viscosity, and particle size distribution on a 50 inch diameter cyclone are shown in figures 6-12 and 6-13. These figures illustrate the dependence of cyclone collection efficiency on those variables and the importance of maintaining proper gas inlet conditions.

*b. Field performance.* The actual in-field performance of cyclone units will vary because of changes in operating conditions such as dust load and gas flow. Table 6-2 illustrates the optimum expected performance of cyclone units for particulate removal application in combustion processes.

Table 6-2  
Removal of uncontrolled particulate emissions  
from combustion processes

<u>Source</u>	<u>Cyclones</u>	
	<u>Conventional</u>	<u>High Efficiency</u>
	percent removed	
Coal fired:		
1. Spreader, chain grate, and vibrating stokers	70-80	80-90
2. Other stokers	75-80	90-95
3. Cyclone furnaces	20-30	30-40
4. Other pulverized coal units	40-60	65-75

From EPA-42, "Compilation of Air Pollution Emission Factors," 3rd edition.



Curve 1 = cyclone body diameter  
 Curve 2 = cyclone gas outlet diameter  
 Curve 3 = cyclone inlet width  
 Curve 4 = cyclone inlet height

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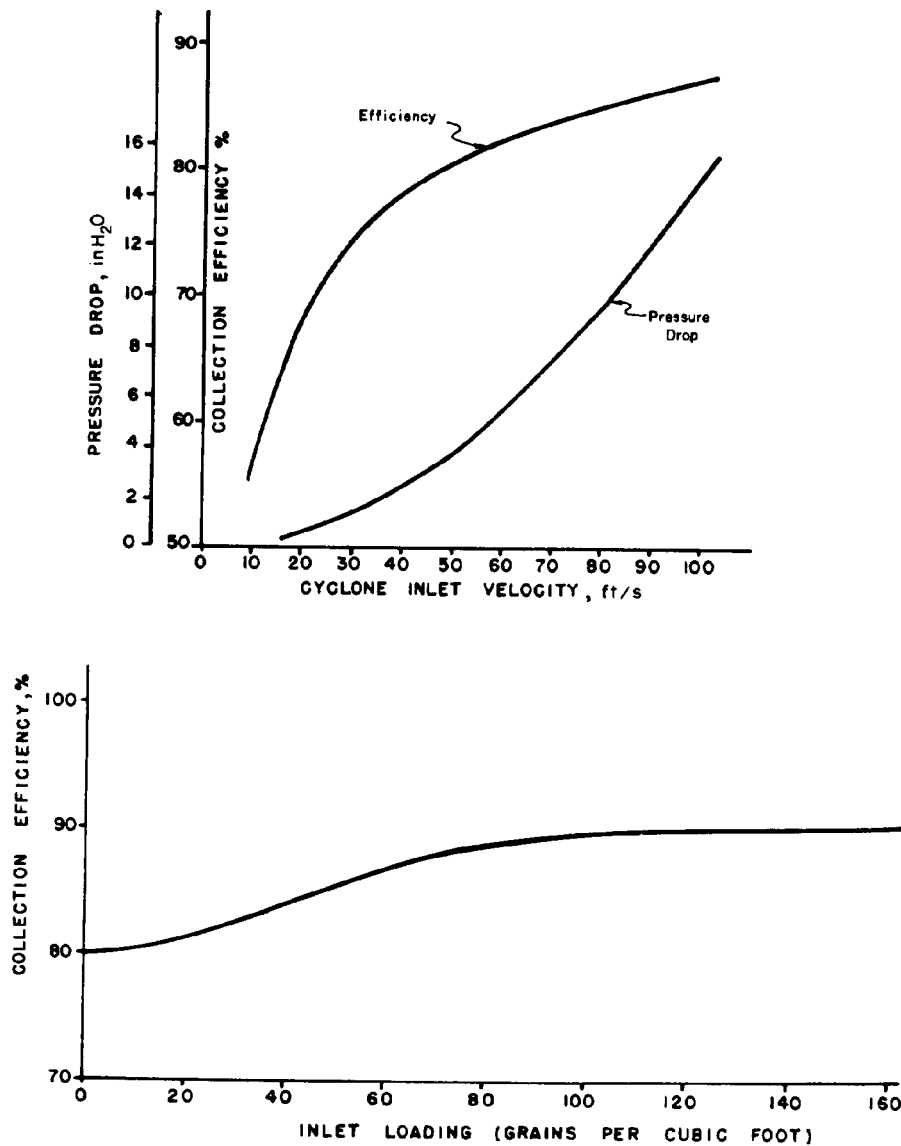
Figure 6-11. Effect of altering individual cyclone dimensions on theoretical collection efficiency for an 8-inch diameter cyclone

## 6-7. Cyclone operation

*a. Erosion.* Erosion in cyclones is caused by impingement and rubbing of dust on the cyclone walls. Erosion becomes increasingly worse with high dust loading, high inlet velocities, larger particle size, and more abrasive dust particles. Any defect in cyclone design or operation which tends to concentrate dust moving at high velocity will accelerate erosion. The areas most subject to erosive wear are opposite the inlet, along lateral or longitudinal weld seams on the cyclone walls, near the cone bottom where gases reverse their axial flow, and at mis-matched flange seams on the inlet or dust outlet ducting. Surface irregularities at welded joints and the annealed softening of the adjacent metal at the weld will induce rapid wear. The use of welded seams should be kept to a minimum and heat treated to maintain metal hardness. Continuous and effective removal of dust in the dust outlet

region must be maintained in order to eliminate a high circulating dust load and resultant erosion. The cyclone area most subject to erosion is opposite the gas inlet where large incoming dust particles are thrown against the wall, and in the lower areas of the cone. Erosion in this area may be minimized by use of abrasion resistant metal. Often provisions are made from removable linings which are mounted flush with the inside surface of the shell. Erosion resistant linings of troweled or cast refractory are also used. Dust particles below the 5 to 10 micron range do not cause appreciable erosion because they possess little mass and momentum. Erosion is accelerated at inlet velocities above approximately 75 ft/sec.

*b. Fouling.* Decreased collection efficiency, increased erosion, and increased pressure drop result from fouling in cyclones. Fouling generally occurs either by plugging of the dust outlet or by buildup of



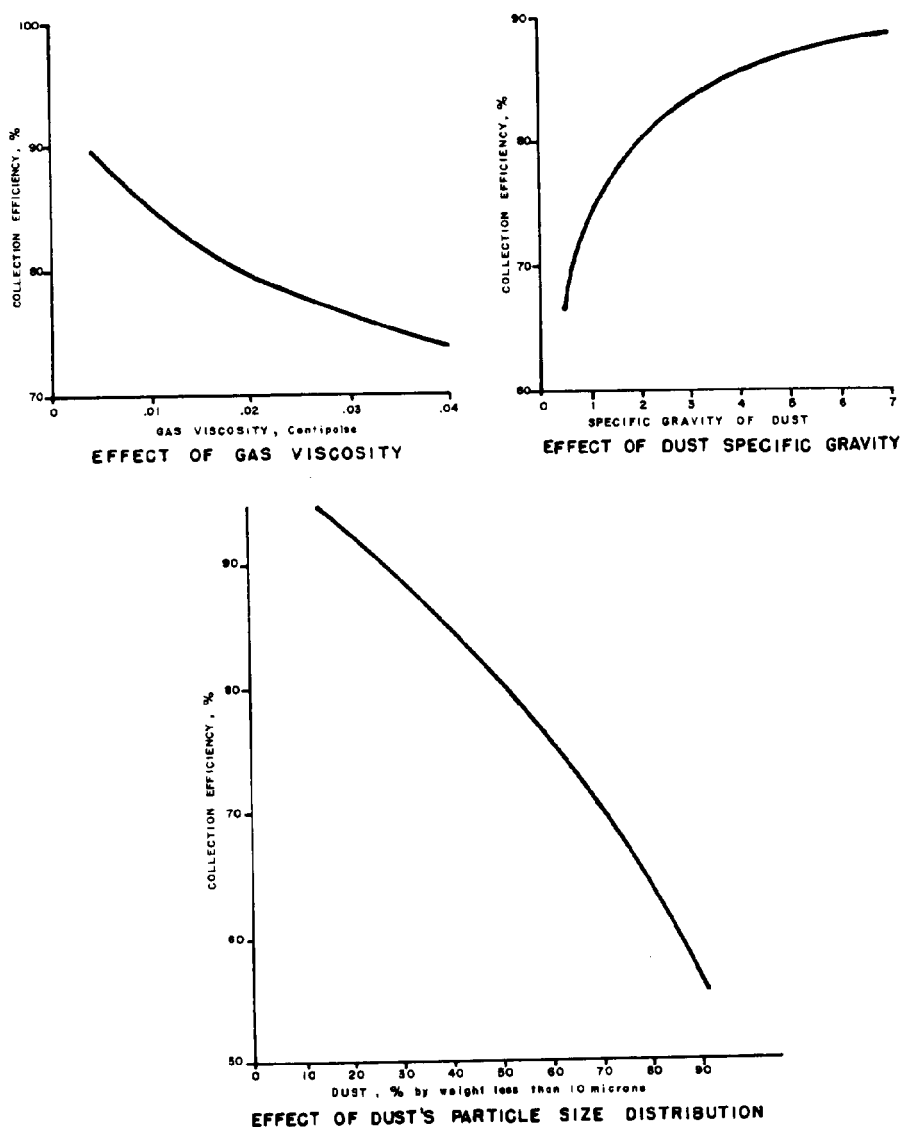
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Figure 6-12. Effects of cyclone inlet velocity and grain loading

materials on the cyclone wall. Dust outlets become plugged by large pieces of extraneous material in the system, by overfilling of the dust bin, or by the break-off of materials caked on the cyclone walls. The buildup of sticky materials on the cyclone walls is primarily a function of the dust properties. The finer or softer the dust, the greater is the tendency to cake on the walls. Condensation of moisture on the walls will contribute to dust accumulations. The collector should therefore be insulated to keep the surface temperature above the flue gas dew point. Wall buildup can generally be minimized by keeping the gas inlet velocity above 50 ft/sec.

c. *Corrosion.* Cyclones handling gases containing

sulfur oxides or hydrogen chloride are subject to acid corrosion. Acids will form when operating at low gas temperatures, or when the dust hopper may be cool enough to allow condensation of moisture. Corrosion is usually first observed in the hopper or between bolted sections of the cyclone inlet or outlet plenum spaces where gasketing material is used and cool ambient air can infiltrate. Corrosion at joints can be minimized by using welded sections instead of bolted sections. Ductwork and hoppers should be insulated and in cold climates the hoppers should be in a weather protected enclosure. Heat tracing of the hoppers may be necessary.



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Figure 6-13. Effects of gas viscosity, dust specific gravity, and dust particle size distribution.

*d. Dust hopper design.* A properly designed dust hopper should be air tight and large enough to prevent the dust level from reaching the cyclone dust outlets. Dust hoppers are usually conical or pyramidal in shape and are designed to prevent dust buildup against the walls. All designs should include a means of continuous removal of dust from the hopper to a storage bin, with an adequate alarm system to indicate a malfunction. Bin level alarms are frequently used for this purpose. On negative pressure systems, hoppers and removal system must be air tight. If hot unburned combustibles or char are present in the collected particulate, introduction of fresh air can cause a hopper fire. Pneumatic ash transport systems are not

recommended for ash containing unburned combustibles or char for the same reason.

## 6-8. Selection of materials

*a. Conditions.* Cyclones can be constructed of a variety of types of metals. The type of materials specified is dependent upon the erosion characteristics of the dust, the corrosion characteristics of the gases, and the operating temperature of the cyclone. Generally, cyclones are constructed of mild steel or cast iron. (See para 7-5 for additional information on materials selection for pollution control systems).

*b. Erosion.* Erosion is the single most important criterion in specifying the materials for cyclone con-

struction. Erosion life of a cyclone may be extended by using harder and thicker grades of steel. A stainless steel of 400 Brinell rating or better is normally chosen for cyclones subject to erosive conditions. When erosion is extreme, it is necessary to provide for replaceable liners in cyclone construction. Liners are made of hard stainless steels or erosion resistant refractory. In low temperature fly ash applications, cyclones of mild steel or iron can be used because dust loadings are generally too small to cause appreciable erosion. Cast iron is most often used in multicyclones in boiler service.

*c. Temperature.* Cyclones operated above 800 degrees Fahrenheit cannot be constructed of mild steels because the metal will creep and form ridges or buckled sections. Above 800 degrees Fahrenheit, nickel-copper bearing steel such as Monel is used to provide added strength. When temperatures are in excess of 1000 degrees Fahrenheit, nickel-chromium steel of the 400 series is used in conjunction with refractory linings. Silica carbide refractories provide excellent protection against erosion and high temperature deformation of the cyclone metal parts.

## 6-9. Advantages and disadvantages

*a. Advantages.* The advantages of selecting cyclones over other particulate collection devices are:

- No moving parts,
- Easy to install and replace defective parts,
- Constructed of a wide variety of materials,
- Minimum space requirements,
- Designed to handle severe service conditions of temperature, pressure, dust loading, erosion, corrosion, and plugging,
- Can be designed to remove liquids from gas,
- Low capital costs,
- Low maintenance costs.

*b. Disadvantages.* The disadvantages of selecting cyclones over other particulate collection devices are:

- Lower collection efficiency,
- Higher collection efficiencies (90-95 percent) only at high pressure drops (6 inches, water gauge),
- Collection efficiency sensitive to changes in gas flow, dust load, and particle size distribution,
- Medium to high operating costs.